

National Ignition Facility and Photon Science

The Power of Light

Excitement is growing at NIF as the giant laser nears completion. We are busy preparing for experiments on NIF that will dramatically demonstrate the “power of light.” The 192-beam laser system is a cornerstone of NNSA’s Stockpile Stewardship Program and will serve as a preeminent scientific user facility for decades to come.

In 2007, Laboratory scientists, engineers, and technicians made extraordinary progress on NIF. They commissioned the first of two 96-beam laser bays, firing beams in groups of eight and producing a total of more than 2 million joules of laser energy. NIF’s energy output is already 40 times more than the operating energy of the previous largest lasers. Overall commissioning of NIF is to be complete in March 2009, and fusion ignition experiments are scheduled to begin in 2010.

NIF will provide the first laboratory setting for examining the fusion reactions that occur in supernovae, our Sun and other stars, and nuclear weapons. NIF was designed with three specific research goals in mind: to support stockpile stewardship, show the feasibility of inertial confinement fusion (ICF) as a clean source of energy, and make significant strides in fundamental high-energy-density science. These three missions share the need to prepare materials at extreme conditions—pressures of quadrillions of pascals, temperatures of 100 million kelvins, and densities of 100 grams per cubic centimeter.

NIF was a dream nearly 50 years ago when Laboratory researchers first pointed the way to thermonuclear burn using lasers. NIF is the product of bold and courageous thinking and the innovations of generations of scientists and engineers at Livermore. The work we do on NIF will be key to our future as a premier international research laboratory.

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The night shift in the National Ignition Facility's control room executed shots to commission laser bay 2. The real-time control system is one of the most complex ever designed for a scientific machine.

Commissioning NIF

In the early hours of a July morning, control room operators fired a series of laser shots in a group of eight beams known as Bundle 44. The last shot lasted about 25 billionths of a second, a tiny fraction of the time it takes to blink an eye. The infrared energy of each beam was more than enough to meet NIF's operational and performance qualification requirements. The achievement successfully brought to a close the sequential testing of all 96 beams in laser bay 2, a process that has taken about two years.

Using NIF's state-of-the-art control system, the "owl" shift executed this series of laser shots, without physicists and chief engineers present. In January, NIF extended laser operations to 24 hours, 5 days a week by adding a second shot operations shift covering the period from 1 to 7 a.m. Extended operations allowed a 130-shot performance campaign and a large number of controls test shots and reliability testing to be completed more quickly than previously planned.

Installation of optics and other components in NIF's laser bay 1 is well over 90 percent complete, and preliminary testing is under way. In December, workers began installing the first of 192 integrated optics modules onto the target chamber. These devices are the final components through which a laser beam passes before it enters NIF's target chamber. Each module contains crystal plates that convert the laser light from infrared to ultraviolet. Installation of the optical assemblies will continue through 2008.

Tests and sophisticated computer simulations confirm that NIF is well on the way to reaching its design specification of 1.8 million joules of ultraviolet energy when overall commissioning of the beamlines is complete. The tests measured the quality of each beam's spatial profile and temporal pulse shape. Even though



All of the beams in laser bay 2 have been commissioned. Eight laser beams are encased in each of the 12 "bundles" on the left.



Workers in clean-room garb install one of the first integrated optic modules onto the target chamber. These final optics are assembled in a newly built clean room.

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each shot is exceedingly short in time, its energy output and frequency are designed to vary significantly throughout its duration to meet the specific needs of the experiment being conducted.

Countdown to Ignition

The National Ignition Campaign (NIC) encompasses all experiments, hardware, and infrastructure needed to carry out the initial ignition experiments in 2010 and continuing research in the following years. NIC is managed for NNSA by the Laboratory and also includes Los Alamos and Sandia national laboratories, the Laboratory for Laser Energetics at the University of Rochester, and General Atomics of San Diego. NIC's goal is to use NIF laser energy to demonstrate ICF—compressing and heating a millimeter-size target filled with deuterium and tritium (DT) to achieve fusion ignition and the generation of more energy than is input. The NIC team will also transition NIF to routine operations as a highly flexible high-energy-density science facility by 2012.

The first experiments using 96 beams are scheduled for 2009 and will help select the optimum radiation temperature for the hohlraum that encloses the target capsule in ignition experiments. Computer simulations are helping to guide the design of the 96-beam experiments. As highlighted in the October 1, 2007, *Nature Physics*, a set of simulations very closely matched data from NIF Early Light experiments conducted in 2003–2004 that studied the interaction of intense laser light with hot plasmas. The results indicate that NIF's laser beams will propagate effectively through the hot plasma generated in fusion experiments and will achieve ignition.

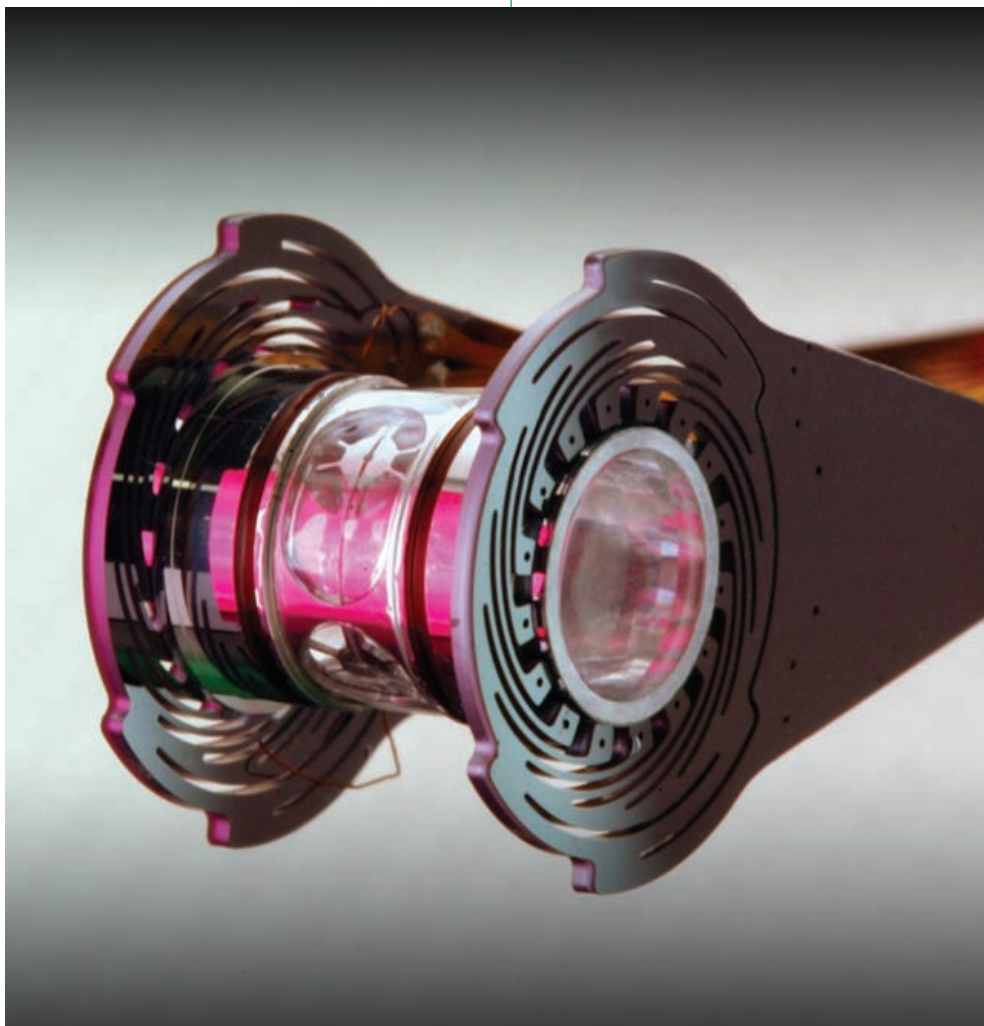
The Target Challenge

A major component of NIC is the development of systems for ignition targets,

which comprise three areas: integrated target systems, cryogenic target positioner systems, and target diagnostics systems. In 2007, the main thrust in all three areas was to prepare for the 2009 experimental campaigns to validate the target's design.

NIC targets generally consist of a capsule assembly, hohlraum, and a surrounding thermal-mechanical package. Their manufacture presents challenges in coatings, micromachining, laser machining, characterization, and assembly. Several development efforts focused on the capsule assembly, which is a sputter-coated, copper-doped beryllium shell with a fill tube attached. New methods for coatings and laser machining yielded production processes that

A fully assembled target for ignition experiments incorporates a tented capsule, hohlraum, thermal-mechanical package, and silicon cooling arms.



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A target alignment sensor positioner ensures that targets are aligned with all 192 laser beams.

meet specifications for retention of the DT gas fuel as well as for the geometry and allowable defects at the fill hole.

The hohlraum incorporates a layer of sputtered gold and uranium whose stability has been problematic because of uranium's reactive nature. A new uranium deposition process has resulted in far greater stability. New fabrication processes are being pursued to increase production rates for both the capsule assembly and the hohlraum to meet the demands of NIC's planned experiments. A new clean room at General Atomics houses metrology equipment for target subcomponents. In addition, Livermore commissioned a clean room for final assembly of targets on a scale that meets NIC needs.

The NIC cryogenic targets include a thin layer of DT ice on the inside of the beryllium shell. The ice surface must be almost perfectly smooth so that the capsule implodes symmetrically. A new process for rapidly cooling DT to the required temperature results in a smoother ice surface than the previous slow-cooling method. The targets must be used quickly before the smoothness of the rapidly cooled ice layer begins to deteriorate.

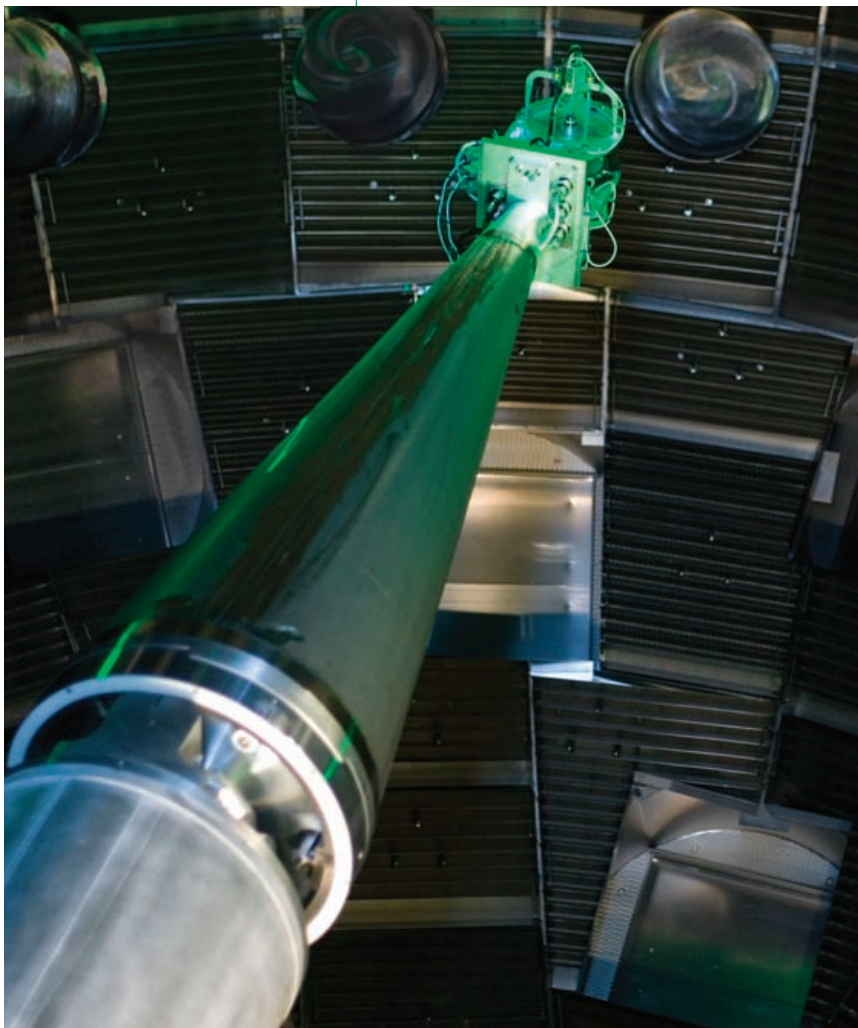
Early in 2007, the first ignition target inserter cryostat was assembled and tested in the process integration laboratory's vacuum vessel. The cryogenic system demonstrated the ability to meet the temperature stability requirements of less than 1 millikelvin for the target's ice layer over a 45-hour period. NIF's existing target positioner for noncryogenic targets is being modified to accommodate the inserter cryostat and cryogenic targets. The cryogenic target positioner places the target assembly precisely in the center of the target chamber, where the target alignment sensor positioner aligns the target with NIF's laser beams.

The target diagnostics systems, originally fielded for the NIF Early Light experimental campaign several years ago, are being upgraded and reinstalled on the target chamber. New diagnostic equipment required for the shot campaigns is being readied for installation and commissioning.

Some experiments on NIF will not require fusion ignition and call for different kinds of targets. In parallel with NIC target development, Livermore scientists are experimenting with a variety of extremely low-density foams, graded-density foams, and other specialized materials from which nonignition targets will be fabricated.

After Ignition

All of these activities at NIF, as well as ongoing experiments at the OMEGA facility at the Laboratory for Laser

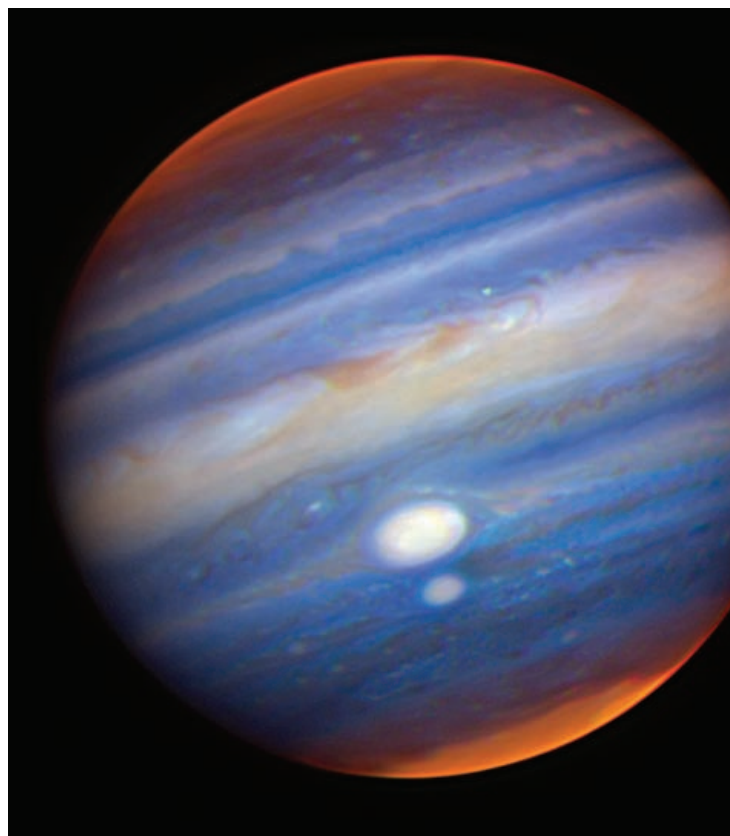


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Energetics at the University of Rochester, focus on achieving ignition. Once that has been accomplished, experiments will support stockpile stewardship and explore high-energy-density physics. When fully operational, NIF will be the only experimental facility capable of creating the temperatures and pressures necessary to study the physics of the nuclear phase of weapons performance. The long-term success of the Stockpile Stewardship Program will rely on a wide variety of ignition and nonignition experiments to help scientists understand underlying issues about nuclear weapon performance and gather data to improve and validate weapons-physics simulation models. Together, experiments and simulations support the annual assessments of the stockpile, investigations of stockpiled weapons systems, decisions about weapons refurbishment or replacement, and certification of weapons modifications (see p. 7).

Ignition experiments will demonstrate the feasibility of fusion as a path to abundant clean energy and are critical to understanding fusion burn, a phenomenon central to the performance of nuclear weapons. Ignition and thermonuclear burn are complex processes in weapons that involve the physics of hot, dense plasmas—a regime that is not fully understood. In NIF experiments, scientists will gather key data that can help them improve the physics in computer codes. For example, in 2007, NNSA launched an initiative to improve understanding of the process by which fusion reactions increase the fission output of weapons. This initiative will require a significant effort over many years, including the use of NIF as a source of experimental data.

Nonignition experiments at NIF will give researchers additional information about the performance of a nuclear weapon during its nuclear phase. The new data, which also pertain to basic science issues, will include information about equations of state at



The National Ignition Facility will be used by physicists from around the world. One team has already formed to use NIF experiments to study the interiors of huge planets, such as Saturn and Jupiter.

pressures up to quadrillions of pascals, opacity (the absorption and transmission of x rays by materials at weaponlike temperatures), and the strength of solid materials at pressures of trillions of pascals under dynamic conditions. NIF is unique in its capabilities for these experiments because of its excellent diagnostic tools and its ability to produce very high temperatures in a large enough volume for a sufficiently long period of time.

A Community of Users

In August, about 70 scientists from the U.S. and Europe gathered in Livermore for a NIF nuclear astrophysics workshop. This meeting was the first in a series of “Science Use of NIF” workshops that will help lay the groundwork for NIF’s evolution into an international center for experimental science. Researchers at the workshop

brainstormed experimental topics and discussed additional diagnostic devices that might be required for experiments on how the universe operates at both the smallest and the largest scales. Additional workshops in a variety of physics areas are planned for 2008.

Already four research teams have formed and received seed grants from the Laboratory to design experiments and targets for NIF shots. The teams, comprising scientists from institutions around the U.S., will initially examine four high-energy-density problems. The first team will study the response of materials to enormous pressures such as those found in the interiors of Jupiter and Saturn; the second, the kinds of turbulent hydrodynamic processes that affect the evolution of supernovae; the third, the instabilities that occur when lasers interact with large-scale plasmas; and the fourth, some of the nuclear reactions that

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occur in stars. Livermore scientists will serve as liaisons between the groups and NIF to help field their experiments and interpret the results.

The Laboratory has created a NIF Users' Office and is drafting a governance plan for proposing and conducting experiments on NIF. One goal of the outreach effort is to find a mechanism for providing additional seed grants over the next several years so that other university teams can develop experiments for NIF.

Photon Science Advances

Mercury, a single-beam laser, is serving as a test bed for the laser driver technology that will be essential for a practical inertial fusion energy power plant. NIF operations permit all 192 beams to fire simultaneously only once every few hours. Thousands of optics must cool before they can properly function again. For Mercury, Laboratory scientists have developed a method of continuously cooling the optics, allowing the laser to fire rapidly over extended periods. As laser pulses pass through the optics at a rate of 10 per second, high-velocity helium gas is propelled across

the optics to keep them cool. In Mercury, diode lasers have replaced NIF's 7-foot-tall flashlamps, increasing efficiency and reducing heat output. Mercury is designed such that it could be scaled up to the size needed for a fusion energy plant. A future fusion power generating facility would combine the energy output of NIF with the rapid-fire shot capability of a Mercury-like laser to supply virtually inexhaustible energy.

Mercury is just one example of the innovative work under way on photon science and applications at the Laboratory. A team of experts on advanced optical components is designing and fabricating a variety of custom diffractive optics for Laboratory projects and for researchers worldwide. The Advanced Radiographic Capability is extending Livermore's expertise in high-energy petawatt lasers for use in multiframe, hard-x-ray radiography of imploding NIF capsules, a diagnostic tool that is critical to the success of proposed future experiments at NIF. Progress also continues on the solid-state heat-capacity laser, which is setting the stage for both tactical and strategic laser weapons in the coming decade (see p. 19).

An award-winning wavelength converter is a critical element of the Mercury laser. The yttrium-calcium-oxyborate crystal in the center of the holder shifts the wavelength of invisible infrared light on the right to green light on the left.

